Prefabricated bridge innovations

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ABSTRACT: This paper describes advantages and recent innovations in the use of prefabricated bridge elements and systems, highlighting uses throughout the country.

1 BRIDGE PREFABRICATION FOR BETTER BRIDGE PROJECTS

Prefabricated bridge elements and systems are typically constructed off-site and brought to the project location ready to erect. They can also be constructed adjacent to the project site, out of the way of traffic, and then moved into position when they are needed. They can range from individual prefabricated elements, such as beams or caps, to completely prefabricated bridges. Their use benefits bridge owners, designers, and contractors by minimizing traffic disruptions, increasing work-zone safety, reducing environmental impact, improving constructibility, and increasing quality while lowering cost.

In 2001, the American Association of State Highway and Transportation Officials (AASHTO) Technology Implementation Group (TIG) selected Prefabricated Bridge Elements and Systems as a first-round focus technology. The TIG champions the implementation of ready-to-use focus technologies that offer significant economic or qualitative advantages. The TIG Panel on Prefabricated Bridge Elements and Systems has developed a web site—http://www.aashtotig.org/focus_technologies/prefab_elements/—promoting this technology and the advantages it offers.

1.1 *Minimized traffic disruption*

The interstate highway system is approaching its service life at the same time that urban congestion is increasing. However, the traveling public has lost patience with highway construction delays that slow progress to and from workplaces and impede commerce. Bridge construction can be a bottleneck because of its sequential nature—foundations required before columns and caps, and columns and caps required before beams and deck—and because of requirements for curing of concrete. Use of prefabricated bridge elements and systems allows moving portions of construction, such as fabrication of components, away from the construction site and its traffic. Time-consuming tasks like formwork erection and removal, steel reinforcement and concrete placement, and concrete curing no longer need to be accomplished in the work zone. Prefabricated components can be transported to the bridge site and quickly erected in place. Conventionally sequential processes can occur off-site concurrently with on-site construction.

1.2 *Increased work-zone safety*

Construction sites often require workers to operate close to moving traffic, over water, at high elevations, near power lines, or in other dangerous situations. Prefabrication allows bridge construction activities such as concrete placement and curing to occur in safer surroundings, greatly reducing the amount of time that workers must operate in potentially dangerous settings.

1.3 *Reduced environmental impact*

Conventional bridge construction requires significant access underneath the bridge for construction personnel and equipment to perform activities such as erection of formwork and placement of steel reinforcement, which are necessary to construct the bridge. Using prefabricated bridge elements and systems gives the contractor more construction options, including top-down construction in sensitive wetlands, and can reduce the effect on the adjacent landscape. On-site construction time is also reduced. This flexibility facilitates bridge construction and can be especially beneficial in environmentally sensitive areas.

1.4 *Improved constructibility*

Job locations vary considerably, and each site imposes unique construction constraints. Problematic job sites might include heavy traffic on an interstate highway that runs under a neighborhood bridge, high elevations, long stretches over water, and work zones restricted by adjacent development. Using prefabricated bridge elements and systems to move much of the work off-site relieves constructibility pressures.

1.5 *Increased quality and lower life-cycle cost*

Prefabrication can be accomplished outside the bridge erection schedules and off the construction site in a controlled environment. The controlled environment reduces dependence on weather and increases quality control of resulting products. Established materials suppliers ensure consistent quality of materials. Plant operations are standardized, ensuring consistent quality of production. Curing of prefabricated concrete components can be more closely monitored, and inspection to ensure quality is easier in a plant than in the work zone.

Including cost of construction delays to bridge users in cost comparisons of cast-in-place versus prefabrication typically shows that prefabricated elements and systems are much more cost competitive than conventional construction because of the significantly reduced on-site construction time. Improving quality of construction also improves bridge durability, resulting in a longer service life and even lower life-cycle cost.

2 BRIDGE ELEMENTS AND SYSTEMS THAT CAN BE PREFABRICATED

Because of new and emerging materials and equipment, bridge elements and pre-assembled systems of bridge elements—sometimes even entire bridges—can now be prefabricated. Prefabrication of bridge elements and systems saves time, solves project-specific challenges, and increases the quality of bridges by moving fabrication to a controlled environment.

2.1 *Deck*

Prefabrication offers opportunities for removing deck placement from the critical path of bridge construction schedules, cost advantages for deck placement, and for quality benefits for the deck itself:

- Partial-depth prefabricated deck panels act as stay-in-place forms to speed construction and allow more controlled construction for a more durable deck than fully cast-in-place decks.
- Full-depth prefabricated bridge decks facilitate and speed construction. Innovative ways to connect full-depth panels are constantly being developed.

2.2 *Bent caps*

Prefabricating bent caps eliminates on-site form erection and concrete curing times. It can reduce the time that workers need to operate over-water while placing concrete. It reduces formwork required, thereby limiting traffic disruption to traffic. And it limits the time that workers are at risk on jobs with location-specific dangers.

2.3 *Columns*

Precast columns on cast-in-footings or drilled shafts can reduce on-site construction times. Columns can be segmental, post-tensioned, either hollow or concrete-filled.

2.4 *Total superstructure systems*

Entire segments of the superstructure can be prefabricated, offering tremendous potential advantages in terms of constructibility, on-site construction time, and the need to have equipment on the construction site:

- Preconstructed units may include steel or concrete girders prefabricated with a composite deck, cast away from the project site and then lifted into place in one operation.
- Truss spans can also be prefabricated.

2.5 *Total substructure systems*

Individual piers or a prefabricated bent cap supported by prefabricated columns comprise a total substructure system. In addition to cost, time, and quality advantages, reduced need for on-site substructure construction can limit negative effects of construction in environmentally sensitive areas.

2.6 *Totally prefabricated bridges*

Totally prefabricated bridge systems facilitate rapid construction and depend on a range of prefabricated bridge elements that are transported to the work site and assembled in a rapid-construction process.

3 INNOVATIVE USES OF PREFABRICATION IN BRIDGE PROJECTS

Although prefabricated beams and girders have long been used in bridge construction, innovative bridge owners, designers, and builders have applied the technology to increasingly complex elements and systems.

3.1 *Decks*

Partial-depth deck panels act as stay-in-place forms, reducing the volume of site-cast concrete and eliminating formwork removal. Full-depth deck panels go even further toward reducing on-site construction. Proprietary brands of prefabricated full-depth deck panels are commercially available.

3.2 *Partial-depth deck panels in Texas*

In 1963, the Texas Department of Transportation (TxDOT) developed a composite concrete bridge deck system consisting of precast concrete panels in the lower half with cast-in-place concrete completing the upper half of the deck. This partially-prefabricated deck system caught on slowly, but now panels are typically the contractor-preferred system for constructing bridge decks, and most bridges in Texas are constructed with panels. TxDOT-sponsored research showed that use of precast pretensioned concrete deck panels produces a deck that is stronger, stiffer, and more crack-resistant to applied loads than a conventional cast-in-place concrete deck (Tsui et al. 1986). Texas girder-type bridge plans allow deck panels as a contractor option, and the contractor typically chooses this option because it speeds deck construction, improves worker safety during construction, and lowers costs.

3.2.1 *Full-depth deck panels—Reedy Creek Bridge in Orlando, Florida*

The main entrance to Walt Disney World in Orlando includes a new bridge constructed entirely from the top down. Although owned privately, it was designed to meet Florida Department of Transportation standards and also to avoid any effect on the creek bed below. The winning contractor and engineer fulfilled requirements by using precast pile caps and full-depth deck panels.

Interior deck panels were nominally 6 ft. wide and haunched, 15 in. deep at the center and 24 in. deep at the ends. Exterior constant 24-in. deep deck panels, tapering in width from a minimum 1 ft. 9 in. with depth equal to the haunch of the typical panels, provided simple constant-depth bridge lines. The 104 pile caps were identical except for the length and number of conical holes for integration with the steel pipe piles. The shallow precast pile caps and precast deck panels produced a total depth of less than 5 ft., with the deck itself only 2 ft. 5 in. Shear keys between panels and the reinforced concrete overlay were the only cast-in-place concrete.

The contractor drove the steel piles and erected precast components from a traveling erection platform.

Photo courtesy of BERGER/ABAM Engineers Inc.

Figure 1. Reedy Creek Bridge in Orlando, Florida.

3.2.2 *Spur 326 Bridge over AT&SF Railroad in downtown Lubbock, Texas*

In 1988, TxDOT rehabilitated two separate structures over a railroad in downtown Lubbock because of early deck deterioration and the need to widen the roadway. The new deck included eight precast full-depth panels, each 6 ft. 3 in. by 45 ft. by 8 in. Panels were epoxied into place, and on-site construction took only a couple of days.

3.3 *Bent caps*

Massive concrete bent caps require extensive formwork and concrete curing times. Prefabrication takes these requirements out of the critical path of construction schedules.

3.3.1 *State Highway 36 over Lake Belton Bridge near Waco, Texas*

Twin bridges, currently being built near Waco, will be 3,840 ft. long with 62 interior supports. They will be constructed entirely over water. Lake surface elevations fluctuate significantly, and designers concerned about the performance of underwater precast column joints chose a cast-in-place twin-column arrangement with precast bent caps. The 62 repeating supports made precast bent cap construction a cost-effective solution over conventional cast-in-place bent cap construction. The hammerhead bents on this project require the highest moment-demand cap-to-column connections on precast caps in Texas to date.

Photo courtesy of Texas Department of Transportation

Figure 2. Hammerhead bents on Lake Belton Bridge near Waco, Texas.

3.4 *Columns*

As an alternative to cast-in-place columns, prefabricated columns can save on-site construction time, limiting the need to obstruct traffic at the construction time.

3.4.1 *Dallas/Fort Worth International Airport People Mover*

Scheduled for completion in 2004, the Dallas/Fort Worth International Airport's upgrade of its Airport People Mover System must accommodate new terminals and increased passenger counts, transporting passengers between farthest terminals in no more than 11 minutes. Because of high daily costs for using airport apron space for casting concrete, the People Mover team designed and built a precast post-tensioned segmental system of columns that can be cast off-site and then assembled on the apron to limit closures of aircraft terminals and gates.

Photo courtesy of STOA/Carlos + Law, AE.

Figure 3. Erecting columns for the Dallas/Fort Worth International Airport People Mover.

3.5 *Total superstructure systems*

Recent innovations have combined prefabricated bridge elements into bridge systems—prefabricated, assembled, and installed as units.

3.5.1 *Tied-arch bridges in Houston, Texas*

In 1998 a multi-decade effort to increase capacity on US 59 reached the Museum District near downtown Houston. However, before TxDOT could add two high-occupancy vehicle lanes and two travel lanes, it needed to replace four continuous post-tensioned concrete bridges spanning the freeway. US 59 is depressed through the Museum District, severing residential neighborhoods that are connected only by the bridges. Key requirements for the bridge replacement work were minimal disruption to the 250,000 vehicles per day that use the freeway as well as maintaining the surface profile of the streets above the freeway due to residential driveways immediately adjacent to the bridge ends. In order to provide minimum clearance below the new bridges, minimize roadway user costs, and avoid skewed ends, a structural system was needed that could clear-span 218 ft. with an apparent structure depth of one foot, about the thickness of typical concrete pavement on Houston freeways.

The new steel tied arch bridges clear span 224 ft. over the freeway and carry two lanes of traffic, two bicycle lanes, and a utility parapet in each direction, and sidewalks outside of each arch. The arches, 45 ft. apart, are fabricated from steel plate and braced with rectangular structural tubing. The deck is comprised of full-width precast and prestressed panels that are post-tensioned longitudinally and overlaid with composite concrete. Superstructures for all four bridges are exact duplicates, resulting in economies in design, fabrication, and construction. Installation of the new structures was achieved on top of the existing structures.

Each bridge was replaced with only one weekend closure: there were no other effects on traffic during construction. Several steps were taken to maintain freeway traffic under the bridges during all phases of construction. The arches were located to fit within the existing bridge width so that they could serve as a work platform. The light-weight steel arches were shored from the existing bridge deck. The length of the new bridges enabled construction of the abutments without affecting the existing bridges. There were no effects on traffic during this phase of the work. Once the steel arches were in place, straddling the existing bridges, the contractor used explosives to drop the old bridges down to freeway pavement level where workers broke up the concrete using conventional methods. The speed of steel erection also enabled TxDOT engineers to minimize duration of street closures.

Photo courtesy of Texas Department of Transportation

Figure 4. Totally prefabricated superstructure system on tied-arch bridge in Houston, Texas.

3.5.2 *New York State Thruway Overpass at Route 100 in New York*

In 1997 a gasoline tanker truck explosion and fire caused extensive damage to a 150-ft. long overpass used to carry six lanes of traffic and necessitated total superstructure replacement. Traffic was rerouted for approximately 12 days while the damaged bridge was demolished, and temporary footings were placed beyond the damaged abutments to accommodate two temporary bridges, each carrying two lanes of traffic. Then the new bridge was built. The new structure used 12 proprietary prefabricated modular full-depth deck panels. As sufficient portions of the new bridges were replaced, traffic was rerouted to the new portion of the structure, and the temporary bridges were removed. Enough time was saved using the prefabricated deck panels to entitle the contractors to approximately $40,000 in bonuses.

3.5.3 *Louetta Road Overpass on State Highway 249 near Houston*

Constructed in the mid-1990s, the Louetta Road Overpass has prefabricated piers, with each pier consisting of several precast hollow-core high-performance concrete segments containing six post-tensioned bars. After the foundation for the overpass was completed, the prefabricated segments were erected and the bars were then tensioned. Using prefabricated piers significantly reduced construction time.

Photo courtesy of Texas Department of Transportation

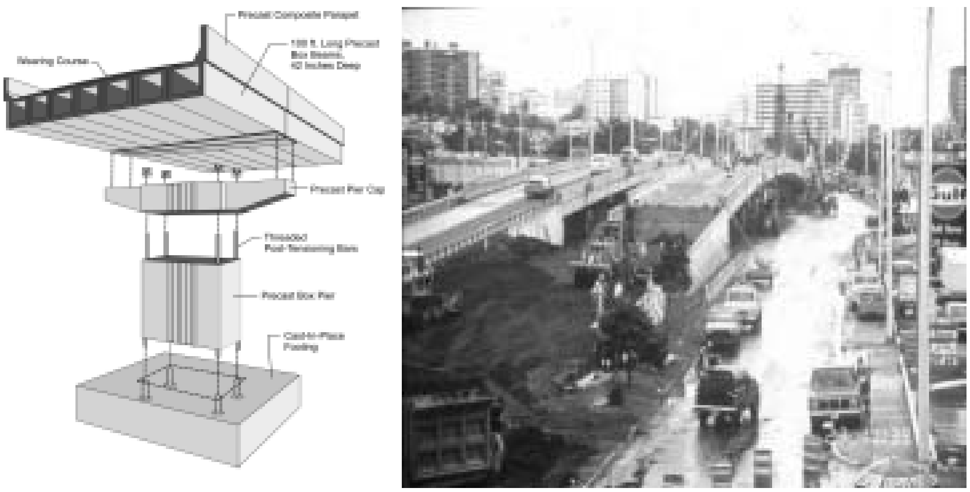
Figure 6. Precast piers at Louetta Road Overpass on State Highway 249 near Houston, Texas.

3.6 *Totally prefabricated bridges*

Some of the most exciting uses of prefabrication are demonstrated by totally prefabricated bridges, which offer maximum advantage for rapid construction. In this application, prefabricated bridge elements are assembled on site in a rapid construction process.

3.6.1 *Baldorioty de Castro Avenue Bridges in San Juan, Puerto Rico*

The Department of Transportation and Public Works in Puerto Rico owns two totally prefabricated overpasses constructed at each of two at-grade intersections that carry over 100,000 vehicles per day. Each of the four bridges, which were 700 ft. long in one intersection and 900 ft. long in the other, was built in three stages, over three weekends in 2001. On the first weekend, piles were driven, on the second weekend footings were cast in place and asphalt was placed to support at-grade traffic, and on the third weekend the footings were uncovered and the prefabricated substructure components were erected and post-tensioned. After the first two substructures at the middle of the bridge were constructed, the 100-ft. long superstructure span was set in place, complete with seven box beams, wearing surface, and parapets. Using two crews, the remaining spans were then erected simultaneously from the center span toward each end, with each span post-tensioned transversely as it was completed. The retaining walls were constructed with select fill on the approaches. The time to complete each overpass ranged from 21 to 36 hours. Commuters used the at-grade intersection on Friday evening and the new overpass on Monday morning.



Drawing and photo courtesy of PCI

Figure 7. Baldorioty de Castro Avenue Bridges in San Juan, Puerto Rico.

3.6.2 *State Highway 66 over Mitchell Gulch Bridge in Colorado*

The Colorado Department of Transportation designed this bridge as three box culverts and then accepted the contractor's proposal to minimize traffic disruption by substituting a single-span structure with side-by-side precast slab girders welded onto precast abutments and wings welded to driven-steel H piles. Except for the steel H-pile supports, the entire bridge substructure was composed of precast concrete elements. The bridge was completed in 2002, and the value-engineering proposal reduced construction detours from an estimated two-to-three months to less than 48 hours.

Photo courtesy of Colorado Department of Transportation
Figure 5. State Highway 66 over Mitchell Gulch Bridge in Colorado.

3.7 *Total substructure systems*

A total substructure system may be prefabricated individual piers or a unit comprised of prefabricated column(s) and cap. These systems require less field time to install than conventional on-site cast-in-place concrete construction. Individual piers are particularly suited to superstructures that consist of a single girder or widely-spaced girders that do not require bent caps.

4 MAKING IT HAPPEN

The use of innovative prefabricated elements and systems does not happen on its own. It takes courageous owners, designers and contractors willing to build effective partnerships and try something new.

4.1 *Innovation doesn't happen on its own*

Sometimes bridge owners have to create the environment that will make innovation happen. An owner who wants to use prefabricated elements or systems may have to specify them. Generally, a contractor inexperienced in the use of prefabrication will not choose prefabrication as an alternate to conventional construction mainly because of the risk incurred when using a new construction method.

For Lake Belton Bridge near Temple, Texas, TxDOT chose to specify a precast cap system. TxDOT did not offer a conventional cast-in-place alternate, and in this way TxDOT was able to make this innovation happen. Anticipated difficulties of managing cast-in-place concrete 40 ft. above the lake and site-specific environmental concerns warranted requiring the use of precast bent cap construction. This structure is currently under construction with two caps being placed each week. With conventional methods, each cap would have taken a full week. By using precast caps, the time for placing the 62 caps was reduced by more than 6 months. Bent-cap prefabrication came at an additional cost of roughly \$400,000 out of a total project cost of \$19,600,000, or about 2%. However, given the success of this project, it is anticipated that similar structures will be built in the future using precast caps at a reduced cost when compared to conventional cast-in-place construction.

4.2 *Build industry partnerships*

Bridge designers need to work with the construction industry to ensure that prefabricated components can be economically produced. Repeatability is an important consideration if the element or system is not standard in the region. Initial bridge construction costs are lowered when the prefabricated element or system is used multiple times—for example, when an identical precast bent cap system is used on a bridge at multiple support locations. For a new prefabricated component to be competitive with conventional construction in initial construction costs, use of the component must be repeated often enough to offset the contractor's cost for formwork and activities associated with fabrication of the component relative to conventional processes. Currently, TxDOT is working with the Texas Precast Concrete Manufacturer's Association to develop a new precast superstructure beam type specifically aimed at rapid construction. This new beam type will almost completely eliminate the necessity for field-placed concrete in the superstructure.

Designers need to keep apprised of the latest technologies in heavy lifting and moving. Recently Mammoet, a company specializing in heavy lifting and transport, moved a 309-ft. long archway structure weighing 1,500 tons over I-80 east of Kearney, Nebraska, in a single lift. To install this archway, the interstate was closed for just 8 hours. The growing technology associated with transport equipment facilitates the installation of totally prefabricated systems.

Photo courtesy of Doug Carroll, Hastings Tribune

Figure 8. Great Platte River Road Archway Monument near Kearney, Nebraska.

4.3 *Tailor prefabricated bridge solutions to the project*

Early in the design process, the bridge designer should consider whether the project will benefit from one or many of the advantages offered by prefabrication: minimizing traffic disruptions, increasing work-zone safety, reducing environmental impact, improving constructibility, and increasing quality and lowering cost. Then prefabricated bridge solutions should be tailored specifically for the project to achieve established goals. For an overpass structure with a busy lower roadway, the use of a totally prefabricated superstructure may be best at meeting the objective of minimizing traffic disruptions. Use of prefabricated partial-depth deck panels may be warranted if speed of construction and worker safety is a priority. For construction over a waterway or wetlands, a totally prefabricated system might provide the best solution to environmental issues. Each project is unique, and the earlier a bridge designer can get involved, the bigger the impact the use of prefabrication can have on the total project.

4.4 *It's not just about construction costs*

Using prefabrication often yields reduced constructions costs, but not always. Look beyond a simple construction cost estimate when deciding whether to use prefabricated elements and systems. Use of prefabrication certainly can provide economical structures when user costs are factored in. Detours and traffic delays come at a considerable cost to the local economy.

The railroad industry recognizes costs above bridge construction costs: for each hour that a rail line is out of service for a bridge replacement, a railroad company estimates losses at \$50,000 to \$100,000. For a simple bridge replacement project this would equate \$1.2M to \$2.4M per day! This cost well exceeds the cost of most simple railroad bridges. For this reason, the railroad industry uses prefabricated structures to the greatest extent possible with many of structures being installed as roll-ins requiring a track outage of just a few hours instead of weeks or months.

In Texas, TxDOT considers the user cost of lane closures on highways when developing contract requirements and incentives/disincentives. For example, in 2003 TxDOT estimated the cost of closing I-10 in Houston during peak hours (5 AM to 9 PM) at \$145,500 per hour and during off-peak hour at \$19,400 per hour. This equates to \$2.5M per day! This far exceeds the cost of a typical overpass structure in Texas. Perhaps roll-ins should not be exclusive to railroad bridge construction. The cost of conventional construction is often less attractive when user costs are factored in.

4.5 *Hidden advantages*

The hidden advantages to using prefabricated elements and systems may outweigh their obvious benefits. In the past contractor incentives and disincentives and performance-based materials specifications have been regarded as "non-bridge" issues, but they can be impacted by the use of prefabricated construction.

By specifying prefabricated elements, the owner can provide contractors with the necessary tools to achieve incentives and avoid disincentives commonly stipulated in today's contracts for such items as early completion and lane closures. By using prefabricated elements, contractors can compress construction operations that were once anticipated to take months into weeks, thereby reducing the length of time needed for construction and the associated traffic control. Similarly, by using precast elements, the contractor can more easily meet the performance-based specifications for concrete quality when high performance concrete (HPC) is specified. Unlike cast-in-place concrete, precast concrete elements can be fabricated in a much more controlled environment. This allows for better quality control for mixing and curing of concrete. When low permeability concrete is required for long-term durability, the use of precast elements can be an easy way to ensure the quality of the finished product.

5 CONCLUSIONS

Agencies nationwide are responding to the public demand to minimize traffic disruptions due to bridge construction. The use of prefabricated elements and systems minimizes the need for cast-in-place concrete in restrictive urban work zones, over water, and in remote and environmentally sensitive areas. With prefabrication, bridges crossing a downtown segment of an interstate can be replaced with minimal lane closures as proven by the US 59 tied-arch bridges in Texas. Environmental impacts can also be minimized through the use of prefabrication as demonstrated by the Reedy Creek Bridge. The use of precast caps can solve constructability issues for bridges over water as was shown on the Lake Belton Bridge. Finally, with prefabrication, an entirely new bridge can appear over a weekend, as shown by the Baldorioty de Castro bridges in Puerto Rico and the Mitchell Gulch Bridge in Colorado.

Interstate highway bridges are approaching the end of their service lives at the same time as traffic volumes and loads are increasing, and the need for rapid bridge rehabilitation and replacement will continue to escalate. With a growing and shifting population, the need for new bridge construction will continue as traffic patterns and volumes change. Innovative bridge design and construction methods are needed to minimize traffic disruption, increase work-zone safety, reduce environmental impact, improve constructibility, increase quality, and lower life-cycle costs of a bridges. Prefabricated bridge elements and systems meet these demands. Work is needed to further improve this innovative technology.

REFERENCES

Tsui, C.K., Burns, N.H., and Klinger, R.E. January 1986. *Behavior of Ontario-Type Bridge Deck on Steel Girders: Negative Moment Region and Load Capacity*. Center for Transportation Research Report 350-3.